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Carbon fractions in soil under no-tillage corn and cover crops in the Brazilian Cerrado

Abstract – The objective of this work was to evaluate soil carbon fractions under cover crops cultivated after corn (*Zea mays*), with or without nitrogen topdressing fertilization, in a long-term experiment in the Brazilian Cerrado. The experiment was carried out in a randomized complete block design, in split-plots with three replicates. The plots were represented by the cover crops, and the subplots, by the presence or absence of N topdressing for corn. The following cover crop species were planted after the harvest of the 30F53VYHR corn hybrid: 'BRS Mandarin' pigeonpea (*Cajanus cajan*), sunn hemp (*Crotalaria juncea*), oilseed radish (*Raphanus sativus*), and black mucuna (*Mucuna aterrima*). After the cutting of the cover crops, soil samples were collected at 0.0–0.10 and 0.10–0.20 m soil depths. After corn harvest, samples of its residues were taken. The cover crops alter the soil chemical and physical fractions, especially fulvic acid and soil particulate organic carbon. Nitrogen topdressing for corn decreases fulvic acid, but increases the humic acid/fulvic acid ratio and particulate organic carbon in the deeper soil layer.

Index terms: *Cajanus cajan*, *Crotalaria juncea*, *Mucuna aterrima*, *Raphanus sativus*, *Zea mays*.

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Frações de carbono no solo sob milho em plantio direto e plantas de cobertura no Cerrado brasileiro

Resumo – O objetivo deste trabalho foi avaliar as frações de carbono no solo, sob plantas de cobertura cultivadas em sucessão ao milho (*Zea mays*), com ou sem adubação nitrogenada em cobertura, em um experimento de longa duração no Cerrado brasileiro. O experimento foi conduzido em delineamento de blocos ao acaso, em parcelas subdivididas, com três repetições. As parcelas consistiram das plantas de cobertura, e as subparcelas, da presença ou da ausência de adubação nitrogenada em cobertura para o milho. As seguintes plantas de cobertura foram plantadas, após a colheita do milho híbrido 30F53VYHR: guandu 'BRS Mandarin' (*Cajanus cajan*), crotalária (*Crotalaria juncea*), nabo-forrageiro (*Raphanus sativus*) e mucuna-preta (*Mucuna aterrima*). Após o corte das plantas de cobertura, amostras de solo foram coletadas às profundidades de 0,0–0,10 e 0,10–0,20 m. Após a colheita do milho, seus resíduos culturais foram coletados. As plantas de cobertura alteram as frações químicas e físicas do solo, principalmente o ácido fúlvico e o carbono orgânico particulado. A fertilização de N em cobertura no milho diminui o ácido fúlvico, mas aumenta a razão ácido húmico/ácido fúlvico e o carbono orgânico particulado na camada mais profunda do solo.

Termos para indexação: *Cajanus cajan*, *Crotalaria juncea*, *Mucuna aterrima*, *Raphanus sativus*, *Zea mays*.



Introduction

Soil organic matter (SOM) is one of the most relevant soil quality indicators, especially in highly weathered Latossolos (Oxisols), in which fertility depends essentially on the SOM quantity and quality. This soil fraction is also critical in the context of global climate change because soils represent the largest C reservoir on the Earth's surface and contribute to the reduction of GHG emissions to the atmosphere (Chenu et al., 2019). Thus, implementing farming systems in the Cerrado biome, without taking the relevance of SOM and soil quality into account, would cause serious problems of degradation, mainly because SOM reduces the potential of storing C in the soil, and decreases its quality for an efficient nutrient cycling (Santos et al., 2014).

Although the plant quality and decomposition dynamics have been investigated (Carvalho et al., 2012, 2015) in corn (*Zea mays* L.) and cover crop succession systems, the results are not sufficiently clear as to the effects of no-tillage corn, preceded by cover crops, on the soil carbon fractions in the Cerrado region.

Corn is one of the most important crops in the world and it is cultivated on 4,905 million hectares in the Cerrado region of Brazil, where the average yield was 5,349 Mg ha⁻¹ in the 2018/2019 growing season according to Companhia Nacional de Abastecimento (Acompanhamento..., 2019). Corn–cover crop succession (Carvalho et al., 2015; Wittwer et al., 2017) in the Cerrado ensures a protective soil cover in the second growing season (Pissinati et al., 2018) against erosion (Anache et al., 2018). Cover crops stabilize soil aggregates (Nascimento et al., 2019) and increase the humic acid and particulate C fractions (Santos et al., 2014), which are the main components of SOM and indicators of the soil quality (Nascimento et al., 2019).

Particulate organic carbon (>53 µm), the most important of the physical fractions, consists of plant, animal, and fungal fragments, and it is the labile fraction that is sensitive to changes in the soil management (Bayer et al., 2002). Secondly, the micro and macroaggregates play an important role in the carbon reserve of the soil (Silva et al., 2016). The chemical fractions consist of labile fractions such as labile carbon, which is also sensitive to soil management, and of the more recalcitrant humic fractions, which are predominant in native Cerrado areas (Nascimento et al., 2017). The humic fractions in

plant residues incorporated into the soil can undergo changes, while the fraction of insoluble humic is least affected by soil management (Hayes et al., 2017).

Humic can be an important carbon reserve because of its insolubility and chemical composition of aliphatic hydrocarbon groups (Hayes et al., 2017) and, to its higher recalcitrance, it ensures a longer persistence in the soil.

The chemical and physical SOM fractions can be altered by the quality and quantity of plant residues (Soares et al., 2019) and management systems (Nascimento et al., 2017). The long-standing use of cover crops, as well as the choice of cover crop species with high biomass production, can contribute to raise the C and N stocks (Bayer et al., 2002; Soares et al., 2019), including the particulate carbon fraction (Santos et al., 2014).

During decomposition, plant residues release C, N, and other nutrients, part of which returns to the atmosphere (Sato et al., 2019), while another part is immobilized by decomposing microorganisms (Paz-Ferreiro & Fu, 2016). The labile fraction remains in the available form to plants (Santos et al., 2014), while nitrate (NO₃⁻) may be lost by leaching (Meisinger & Ricigliano, 2017), and the other soil fractions are the C and N reserves for plants and microorganisms (Santos et al., 2014).

The hypothesis of the present study is that cover crop–corn succession with, or without N topdressing for no-tillage corn, alters the physical and chemical soil organic carbon fractions.

The objective of this work was to evaluate soil carbon fractions under cover crops cultivated after corn, with or without nitrogen topdressing fertilization, in a long-term experiment in the Brazilian Cerrado.

Materials and Methods

The experiment was carried out in an experimental area of Embrapa Cerrados, in Planaltina, DF, Brazil (15°35'30"S, 47°42'30"W, at an altitude of 1,007 m). According to the Köppen-Geiger's classification, the regional climate is Aw, with annual averages of 1,345.8 mm precipitation and 21.87°C temperature.

The soil was classified as Latossolo Vermelho distrófico (Santos et al., 2018), i.e., Oxisol. At the beginning of the experiment, the soil chemical characteristics were as follows: pH (H₂O), 6.0; OM,

21.7 g kg⁻¹; P_{Mehlich-1}, 0.9 mg kg⁻¹; Al³⁺, 0.1 cmol_c kg⁻¹; Ca²⁺+Mg²⁺, 2.9 cmol_c kg⁻¹; K⁺, 0.1 cmol_c kg⁻¹.

Before the experiment, from 1999 to 2004, the area had been used for soybean/corn rotations. No-tillage corn and cover crops were planted in succession, in a long-term experiment (growing seasons 2004/2005 to 2015/2016) in the experimental area. Every year, corn was planted in November and harvested in March, and cover crops were planted in March and harvested at flowering (between May and August), according to the species.

The experiment was arranged in a randomized complete block design, in split plots with three replicates. The plots (12x8 m) consisted of the cover crops, and the subplots (12x4 m) corresponded to corn fertilized with N topdressing (WN), or without N topdressing (NN). The cover crops were: 'BRS Mandarin' pigeonpea [*Cajanus cajan* (L.) Millsp.]; sunn hemp (*Crotalaria juncea* L.); oilseed radish (*Raphanus sativus* L.) and black mucuna (*Mucuna aterrima* Merr.). The N treatments for corn consisted of: N topdressing (WN, 130 kg ha⁻¹ N) and no N topdressing (NN). In both treatments (WN and NN), corn was fertilized with 20 kg ha⁻¹ N at planting. For WN, two topdressings with 65 kg ha⁻¹ N were applied as urea, when plants had the fourth and the eighth pairs of leaves, respectively, that is, a total amount of 150 kg ha⁻¹ N, considering all N fertilizations, as recommended by Sousa & Lobato (2004).

The cover crops were planted at the following sowing densities: 20 plants per linear meter of row for *C. cajan* and *C. juncea*; 10 plants per linear meter of row for *M. aterrima*; and 40 plants per linear meter of row for *R. sativus*, at 0.5 m row spacing.

The cover crops were planted in March 2015, and *R. sativus*, *C. juncea*, *M. aterrima*, and *C. cajan*, respectively, were harvested at flowering in May, June, and August. The cover crop residues were left on the soil surface.

In November 2015, before the corn sowing, soil samples were taken from the 0.0–0.10 and 0.10–0.20 m layers, and composite samples of eight subsamples per layer were blended. The samples were dried in the air, then they were sieved (<2 mm) and stored in the Laboratory of Soil Microbiology of the Universidade de Brasília.

In the same month, 5 viable seeds per linear meter of row of the 30F53VYHR corn hybrid were planted, at

0.75 m row spacing, which resulted in 65,000 plants ha⁻¹ total population. At sowing, the maintenance fertilization was applied in the planting furrows with 500 kg ha⁻¹ of N-P₂O₅-K₂O (4-30-16), together with 2 kg ha⁻¹ Zn (ZnSO₄·7H₂O), and 10 kg ha⁻¹ FTE BR 12 as micronutrient source [chemical composition (%): 3.2 S; 1.8 B; 0.8 Cu; 2.0 Mn; 0.1 Mo; 9.0 Zn; and 1.8 Ca].

Total soil carbon (TC) was determined by dry combustion, using an elemental analyzer (Perkin Elmer 2400 CHN/O, Elementar Analysensysteme GmbH, Hanau, Germany). The particulate soil organic matter (POC) was determined as proposed by Cambardella & Elliott (1992), with adjustments of the sample weight (Bongiovanni & Lobartini, 2006). A sample with 20 g of air-dried soil was placed in 500 mL flasks with 70 mL sodium hexametaphosphate (5 g L⁻¹) and stirred in a horizontal shaker for 15 hours at 130 rpm. After this period, the suspension was sieved (<53 μm) and rinsed with tap water. The material retained on the sieve was dried at 45°C and ground, and the carbon content was determined in an elemental analyzer. Particulate organic carbon was calculated as the difference between sieved C and that contained in the corresponding whole soil sample (53 μm–2 mm), expressed as oven-dried whole-soil.

Mineral-associated organic carbon (MAOC) was calculated as the difference between TC and POC. The calculation of MAOC is an approximation of the organic fraction, since microbial biomass, soluble carbon, and charcoal may be associated with this fraction, and not necessarily with the mineral fraction.

The humic fractions were chemically analyzed according to Swift (1996), using 0.1 mol L⁻¹ NaOH as extractor (extractant: soil ratio 10:1). In this way, the following fractions were calculated: humic acid (C-HA), fulvic acid (C-FA) and humin (C-HUM), according to the principle of differential solubility in an alkaline and/or acid medium. The humin fraction is insoluble at pH > 7 and precipitated in NaOH. The extracted fractions were separated in C-HA and C-FA by acidifying the extract with 6 mol L⁻¹ HCl at pH 1. The precipitate (C-HA) and supernatant (C-FA) were separated by centrifugation for 30 min at 4,500 rpm. Contents of total organic carbon in the humic fractions were determined by wet digestion with potassium dichromate 1 N in an acidic medium (Yeomans & Bremner, 1988), with an external heat source.

In March 2016, 4 m rows of each subplot were harvested to determine corn grain yield (moisture correction to 13%). Straw samples were collected shortly after corn harvest, with two rectangular iron sampling frames per subplot (0.38x0.58 m).

The corn straw samples were dried at 65°C until a constant weight was attained. A subsample of 500 g was weighed to quantify dry plant matter and converted to kilogram per hectare. One portion of the dried samples was ground, and a 3 g sample was heated in a porcelain crucible in an oven at 105°C for 8 hours. Dry matter was calculated as the difference between sample weight before and after this procedure. The total N content (TN) of the straw leaf tissue was analyzed by colorimetry, with a Lachat 228 Quikchem flow injection analyzer (Lachat Instruments, 5600 Lindbergh Drive, Loveland CO 80539 USA).

The dry matter, acid detergent fiber (ADF), neutral detergent fiber (NDF), and lignin contents of the corn straw were analyzed at 105°C (Roberston & Van Soest, 1981). The hemicellulose and cellulose contents were

computed as the differences between NDF and ADF, and between ADF and lignin, respectively.

The analysis of variance was performed using the software R version 3.5.0 (R Core Team, 2019), and the means were compared by the Tukey's test, at 5% probability.

Results and Discussion

The cover crops influenced the chemical (humin and fulvic acid) and physical (particulate organic carbon) fractions of organic C in the two evaluated soil layers (Table 1), but the TC values were similar in both soil layers. Similar TC values at the 0.0–0.10 m layer were also reported by Santos et al. (2014), in soil under the cover crops *C. cajan*, *C. brasiliensis*, *Sorghum bicolor*, and *Urochloa ruziziensis*, after corn cultivation evaluated in the same experimental area in 2013. Authors also concluded that cover crops influenced the carbon chemical and physical fractions,

Table 1. Total soil carbon (TC), carbon fractions in fulvic acid (C-FA), humic acid (C-HA), humin (C-HUM), C-HA/C-FA ratio, particulate fraction of soil organic matter (POC), and mineral-associated organic carbon (MAOC), in a Latossolo Vermelho distrófico soil (Oxisol) under cover crops in rotation with corn (*Zea mays*)⁽¹⁾.

Cover crop	TC	C-FA	C-HA	C-HUM	C-HA/C-FA	POC	MAOC
0.0–0.10 m							
<i>Mucuna aterrima</i>	22.98a	5.93a	2.62a	8.56a	0.44b	2.28ab	20.70a
<i>Raphanus sativus</i>	22.85a	4.93b	3.19a	9.25a	0.67a	2.38ab	20.47a
<i>Cajanus cajan</i>	22.62a	5.87a	2.86a	8.59a	0.49b	2.67a	19.95a
<i>Crotalaria juncea</i>	22.67a	5.47ab	2.50a	8.53a	0.46b	1.92b	20.75a
Fertilization							
WN	22.72a	5.50a	2.90a	8.53b	0.55a	2.33a	20.38a
NN	22.84a	5.60a	2.68a	8.93a	0.48a	2.29a	20.55a
CV% ⁽²⁾	8.15	8.39	19.04	6.08	14.55	10.93	8.71
CV% ⁽³⁾	9.25	10.47	10.76	4.70	18.67	20.28	9.65
0.10–0.20 m							
<i>Mucuna aterrima</i>	17.40a	5.58b	0.84b	7.42a	0.15b	1.65a	15.75a
<i>Raphanus sativus</i>	18.68a	5.34b	1.10ab	7.34a	0.21ab	2.08a	16.60a
<i>Cajanus cajan</i>	20.12a	5.64b	1.25a	7.76a	0.22a	2.28a	17.83a
<i>Crotalaria juncea</i>	18.03a	6.09a	1.23ab	7.38a	0.21ab	1.58a	16.45a
Fertilization							
WN	18.91a	5.30b	1.14a	7.45a	0.22a	2.15a	16.76a
NN	18.21a	6.03a	1.07a	7.50a	0.18b	1.65b	16.56a
CV% ⁽²⁾	7.75	3.39	18.07	3.11	17.35	31.41	8.13
CV% ⁽³⁾	9.84	6.71	20.23	3.57	18.86	25.06	9.37

⁽¹⁾Means followed by equal letters, do not differ by the Tukey's test, at 5% probability. ⁽²⁾Coefficient of variation related to cover plants. ⁽³⁾Coefficient of variation of the fertilization effect. WN, fertilization with N topdressing of corn; NN, no N topdressing of corn.

indicating that soil carbon fractions are more sensitive to soil management than total carbon.

In the 0.0–0.10 m layer, the C-FA content of the soil under *R. sativus* was lower (4.93 g kg⁻¹) than under *M. aterrima* and *C. cajan* (5.93 and 5.87g kg⁻¹, respectively) (Table 1). However, no statistical differences were detected in C-HA, which ranged from 8.53 to 9.25 g kg⁻¹. The C-HA/C-FA ratio was higher in the soil under *R. sativus* (0.67 g kg⁻¹) than in the soil under the other cover crops. The C-HA/C-FA ratio of the soil was <1 in all cover crop treatments, indicating a rapid mineralization of plant residues and humification of soil organic matter (Canellas et al., 2004). The soil humin content (C-HUM) decreased with N topdressing (WN) in corn (Table 1), suggesting a lower accumulation of more recalcitrant compounds against degradation, for being an insoluble fraction, consisting mainly of aliphatic carbon, and long-chain fatty acids and esters (Hayes et al., 2017).

In the 0.10–0.20 m layer, the highest C-FA content occurred in the soil under *C. juncea* (6.09 g kg⁻¹) (Table 1). The C-HA fraction in the soil under *C. cajan* (1.25 g kg⁻¹) differed from the soil under *M. aterrima* (0.84 g kg⁻¹). The content of C-HA and the HA/FA ratio were higher in soil under *C. cajan* (1.25 and 0.22, respectively) and lower under *M. aterrima* (0.84 and 0.15, respectively). Due to N topdressing of corn, the C-FA contents decreased and C-HA/C-FA ratio increased, indicating an intensified mineralization of plant residues in the presence of N fertilizer, which reduced the lignin/N ratio, favoring the straw mineralization. According to Talbot & Treseder (2012), there is an interaction between lignin, cellulose, and N content in plant residues, in which lignin protects cell wall polysaccharides from microbial degradation, and cellulose is a co-substrate for lignin degradation. The N content in plant residues can favor the degradation of residues, mainly by fungi.

The C-HA/C-FA ratio can be considered a good indicator of humus quality, as it expresses the degree of evolution of the humification process of organic matter, and the mobility of C in the soil (Sousa et al., 2015). The C-HA/C-FA ratio ranged from 0.44 to 0.67 g kg⁻¹ in the 0.0–0.10 m layer, indicating a higher degree of humification and, consequently, of mineralization and C mobility, in comparison to the 0.10–0.20 m layer, where it varied from 0.15 to 0.22 g kg⁻¹ (Table 1). Different results for C-HA/C FA were reported by Santos et al. (2014) between soil

layers, in the same experimental setup evaluated three years before, probably due to a shorter period between the settlement of the experiment and the soil sampling.

Regarding the physical fractionation of POC, higher values were detected after corn cultivation in the soil under *C. cajan* than under *C. juncea* in the 0.0–0.10 m layer (Table 1). As POC is a labile carbon fraction associated with aggregate formation and stabilization in the soil (Silva et al., 2016), the soil under *C. cajan* probably releases more nutrients. In the 0.10–0.20 m layer, POC was higher in the WN than the NN treatment, which corroborates the results by Santos et al. (2014), who also described this pattern for *C. cajan* in both layers. This fact indicates that N topdressing increased this carbon fraction, probably due to a more developed root system, which can improve soil aggregation.

The cover crops and N topdressing affected the labile carbon (LC) content of the soil (Table 2). In the 0.0–0.10 m layer, N topdressing of corn after *R. sativus* raised LC to 1.67 times higher content in soil under corn than after *C. juncea*. The highest (0.11 g LC g⁻¹ TC) soil LC/TC ratio occurred the under

Table 2. Labile carbon (LC) fraction and LC in relation to TC, in Latossolo Vermelho distrófico soil (Oxisol) under cover crops in rotation with corn (*Zea mays*) treated with (WN) and without (NN) nitrogen topdressing, in the 0.0–0.10 and 0.10–0.20 m layers⁽¹⁾.

Cover crop	LC (g kg ⁻¹)		TC (g LC g ⁻¹ TC)	
	WN	NN	WN	NN
0.0–0.10 m				
<i>Mucuna aterrima</i>	1.27abA	1.31aA	0.051bA	0.060aA
<i>Raphanus sativus</i>	2.39aA	1.43aB	0.11aB	0.061aA
<i>Cajanus cajan</i>	1.31abA	1.10aA	0.055bA	0.045aA
<i>Crotalaria juncea</i>	0.88bA	1.10aA	0.041bA	0.045aA
CV% ⁽²⁾	48.69		43.42	
CV% ⁽³⁾	21.16		49.83	
0.10–0.20 m				
<i>Mucuna aterrima</i>	1.08aA	0.33cB	0.063aA	0.019cB
<i>Raphanus sativus</i>	1.17aA	1.22aA	0.062aA	0.066a
<i>Cajanus cajan</i>	1.02aA	0.51bcB	0.046aA	0.028bcA
<i>Crotalaria juncea</i>	0.96aA	1.01abA	0.054aA	0.056abA
CV% ⁽²⁾	26.20		21.90	
CV% ⁽³⁾	20.98		24.12	

⁽¹⁾Means followed by equal, lowercase letters in the columns and uppercase letters in the rows, do not differ, by the Tukey's test, at 5% probability.

⁽²⁾Coefficient of variation related to cover plants. ⁽³⁾Coefficient of variation of the fertilization effect. WN, fertilization with N topdressing of corn; NN, no N topdressing of corn.

R. sativus, differing significantly from the other cover crops under WN. This LC/TC ratio under *R. sativus* may indicate that higher levels of readily available sources of C compounds were decomposed rapidly by soil microorganisms, which may have stimulated the metabolism of soil microorganisms and possibly accelerated the initial decomposition of plant residues.

In the 0.10–0.20 m soil layer, LC in soil under *R. sativus* (1.22 g kg⁻¹) was higher than under *C. cajan* (0.51 g kg⁻¹) and *M. aterrima* (0.33 g kg⁻¹) (Table 1), in the NN treatment, and accounted for 6% of the TC. Therefore, *R. sativus* had opposite effects on the studied soil layers in the treatments WN and NN. Similarly to POC, the LC is modified by cover crops and N topdressing (Santos et al., 2014).

Humins accounted for 35 to 40% of TC (HUM/TC) for all cover crops (Table 3), indicating a similar contribution of this fraction to C reserves, for being an insoluble carbon fraction. In the same experimental area, Santos et al. (2014) found ratios between 29 and 33%. Due to its insolubility and chemical composition of aliphatic hydrocarbon groups, humin can be an important C reserve (Hayes et al., 2017), since it remains in the soil longer due to its higher recalcitrance.

In the 0.10–0.20 m layer, the cover plants differed only for the C-FA/TC ratio (Table 3), with higher values in soil under *C. juncea* and *M. aterrima*. Under *C. cajan*, this fraction was 28% of TC.

There was also a significant effect of N topdressing on the soil chemical (C-FA/TC) and physical fractions (POC/TC) in corn (Table 3). The C-FA/TC was higher in the NN (33%) than in the WN treatment (28%), and POC/TC was higher in the WN (11%) than in the NN treatment (9%), indicating that N topdressing of corn alters these fractions, possibly by changing the nutrient dynamics and cycling in the soil.

Corn was planted after cutting the cover crops, and crop residues were analyzed for cellulose, hemicellulose, lignin, and TN contents (Table 4). In all cover crop treatments, the values for cellulose, hemicelluloses, and lignin were similar, due to the higher proportion of corn straw in relation to the biomass production of the cover crops, and the high C/N ratio of corn residues (Carvalho et al., 2012, 2015), offsetting the contribution of the cover crops to straw production.

The total N contents in corn straw were 6.96 and 5.60 g kg⁻¹ in the treatments with nitrogen (WN) and with no N topdressing (NN), respectively (Table 4). This shows that N fertilization of corn (WN) promoted higher N levels in the straw. The lignin/N ratio was 10.21 and 7.95, in NN and WN, respectively, reinforcing the contribution of N fertilization of corn to a higher release of nutrients from residues left on the soil surface, since more TN was accumulated in the straw of the WN treatment. The lower lignin (around 5%) than cellulose content (39% to 42%) indicates that the release of N contained in the straw of the WN treatment is slow.

Table 3. Fractions of fulvic acid (C-FA), humic acid (C-HA), humin (C-HUM), particulate fraction of soil organic matter (POC), and mineral-associated organic carbon (MAOC), in relation to total soil carbon (TC), in Latossolo Vermelho distrófico soil (Oxisol) under cover crops in rotation with corn (*Zea mays*) treated with (WN) and without (NN) nitrogen topdressing, in the 0.0–0.10 and 0.10–0.20 m layers⁽¹⁾.

Treatment	C-FA/TC	C-HA/TC	C-HUM/TC	POC/TC	MAOC/TC	C-FA/TC	C-HA/TC	C-HUM/TC	POC/TC	MAOC/TC
	------(g kg ⁻¹)-----									
Cover crop	0.0–0.10 m					0.10–0.20 m				
<i>Mucuna aterrima</i>	0.26a	0.11a	0.37a	0.10a	0.90a	0.32a	0.048a	0.43a	0.10a	0.54a
<i>Raphanus sativus</i>	0.21a	0.14a	0.40a	0.10a	0.89a	0.29b	0.058a	0.39a	0.11a	0.60a
<i>Cajanus cajan</i>	0.24a	0.12a	0.35a	0.11a	0.87a	0.28b	0.063a	0.39a	0.11a	0.55a
<i>Crotalaria juncea</i>	0.24a	0.11a	0.38a	0.09a	0.91a	0.34a	0.068a	0.41a	0.09a	0.49a
Fertilization										
WN	0.24a	0.12a	0.37a	0.10a	0.89a	0.28b	0.06a	0.40a	0.11a	0.59a
NN	0.24a	0.11a	0.38a	0.10a	0.90a	0.33a	0.06a	0.41a	0.09b	0.50a
CV% ⁽²⁾	10.92	15.52	10.02	14.64	3.17	4.58	19.48	8.22	27.95	29.44
CV% ⁽³⁾	12.51	11.19	6.47	15.68	2.24	10.81	20.15	9.23	19.80	20.49

⁽¹⁾Means followed by equal letters do not differ, by the Tukey's test, at 5% probability. ⁽²⁾Coefficient of variation related to cover plants. ⁽³⁾Coefficient of variation of the fertilization effect. WN, fertilization with N topdressing of corn; NN, no N topdressing of corn.

This is in line with the decomposition models proposed by Fioretto et al. (2005), in which lignin-associated N is released in the first two weeks and associated with cellulose that remains unaltered, during one year of decomposition, and is released more slowly thereafter.

After cover crops in treatments with and without N application, the corn grain yield was 10,827.05 kg ha⁻¹ and 8,333.67 kg ha⁻¹, respectively, that is, the addition of N topdressing resulted in an increase of 23%, due to the high N requirement of the crop (Carvalho et al., 2015) (Table 5). Although cover crops did not

Table 4. Total nitrogen (TN), hemicellulose (HC), cellulose (CL), lignin, and lignin: N ratio in corn (*Zea mays*) residues (collected after maize harvest), in succession to cover crops⁽¹⁾.

Cover crop	TN	HC	CL	Lignin	Lignin:N
	------(g kg ⁻¹)-----				
<i>Mucuna aterrima</i>	6.61a	285.42a	388.60a	52.24a	8.36a
<i>Raphanus sativus</i>	6.08a	288.60a	417.26a	56.99a	9.55a
<i>Cajanus cajan</i>	6.12a	280.15a	418.69a	58.56a	9.77a
<i>Crotalaria juncea</i>	6.31a	285.08a	406.30a	52.60a	8.64a
Fertilization					
WN	6.96a	290.13a	398.30a	53.98a	7.95b
NN	5.60b	279.50a	417.12a	56.21a	10.21a
CV% ⁽²⁾	16.81	5.87	4.54	8.58	21.80
CV% ⁽³⁾	14.40	5.40	4.95	11.72	19.96

⁽¹⁾Means followed by equal letters, do not differ by the Tukey's test, at 5% probability. ⁽²⁾Coefficient of variation related to cover plants. ⁽³⁾Coefficient of variation of the fertilization effect. WN, fertilization with N topdressing of corn; NN, no N topdressing of corn.

Table 5. Dry matter of corn (*Zea mays*) residue, total nitrogen content (TN) in corn residues, and grain yield of corn grown after cover crops⁽¹⁾.

Cover crop	Dry matter (kg ha ⁻¹)	TN (kg ha ⁻¹)	Yield (kg ha ⁻¹)
<i>Mucuna aterrima</i>	8,358.29a	55.44a	9,328.91a
<i>Raphanus sativus</i>	8,277.15a	50.98a	10,152.63a
<i>Cajanus cajan</i>	8,916.29a	54.38a	9,571.39a
<i>Crotalaria juncea</i>	7,015.43a	43.71a	9,268.52a
Fertilization			
WN	8,107.68a	56.37a	10,827.05a
NN	8,175.89a	45.88a	8,333.67b
CV% ⁽²⁾	16.42	17.78	8.634
CV% ⁽³⁾	15.63	25.47	6.32

⁽¹⁾Means followed by equal letters, do not differ by the Tukey's test, at 5% probability. ⁽²⁾Coefficient of variation related to cover plants. ⁽³⁾Coefficient of variation of the fertilization effect. WN, fertilization with N topdressing of corn; NN, no N topdressing of corn.

raise corn yields, they improved the soil properties, increasing the SOM content (Recalde et al., 2015) and its chemical and physical fractions (Santos et al., 2014; Soares et al., 2019). This process is associated with nutrient cycling and accumulation, soil aggregation, and water dynamics, and is also an energy source for soil biological activity (Recalde et al., 2015). Therefore, it is an essential practice to maintain the soil quality.

Conclusions

1. Cover crops alter the chemical and physical fractions of soil (Latossolo Vermelho distrófico), mainly that of fulvic acid, with highest values of this fraction in soils under *Mucuna aterrima*, *Cajanus cajan*, and *Crotalaria juncea*.

2. Cover crops change the soil particulate carbon in the 0.0–0.10 m layer, for which *C. cajan* performs better than *C. juncea*.

3. Nitrogen topdressing fertilization of corn (*Zea mays*) decreases humin in the 0.0–0.10 m soil layer, but increases the humic acid/fulvic acid ratio (C-HA/C-FA) ratio and particulate organic carbon in the 0.10–0.20 m soil depths.

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References

- ACOMPANHAMENTO DA SAFRA BRASILEIRA [DE] GRÃOS: safra 2018/19: décimo primeiro levantamento, v.6, n.11, agosto 2019. Available at: <https://www.conab.gov.br/info-agro/safra/safra/safra-de-graos/item/download/28059_aa1796452a062bb311354e7f32e7e664>. Accessed on: Aug. 10 2019.
- ANACHE, J.A.A.; FLANAGAN, D.C.; SRIVASTAVA, A.; WENDLAND, E.C. Land use and climate change impacts on runoff and soil erosion at the hillslope scale in the Brazilian Cerrado. *Science of The Total Environment*, v.622-623, p.140-151, 2018. DOI: <https://doi.org/10.1016/j.scitotenv.2017.11.257>.

- BAYER, C.; MIELNICZUK, J.; MARTIN-NETO, L.; ERNANI, P.R. Stocks and humification degree of organic matter fractions as affected by no-tillage on a subtropical soil. **Plant and Soil**, v.238, p.133-140, 2002. DOI: <https://doi.org/10.1023/A:1014284329618>.
- BONGIOVANNI, M.D.; LOBARTINI, J.C. Particulate organic matter, carbohydrate, humic acid contents in soil macro- and microaggregates as affected by cultivation. **Geoderma**, v.136, p.660-665, 2006. DOI: <https://doi.org/10.1016/j.geoderma.2006.05.002>.
- CAMBARDELLA, C.A.; ELLIOTT, E.T. Particulate soil organic-matter changes across a grassland cultivation sequence. **Soil Science Society of America Journal**, v.56, p.777-783, 1992. DOI: <https://doi.org/10.2136/sssaj1992.03615995005600030017x>.
- CANELLAS, L.P.; ESPINDOLA, J.A.A.; REZENDE, C.E.; CAMARGO, P.B. de; ZANDONADI, D.B.; RUMJANEK, V.M.; GUERRA, J.G.M.; TEIXEIRA, M.G.; BRAZ-FILHO, R. Organic matter quality in a soil cultivated with perennial herbaceous legumes. **Scientia Agricola**, v.61, p.53-61, 2004. DOI: <https://doi.org/10.1590/S0103-90162004000100010>.
- CARVALHO, A.M. de; COELHO, M.C.; DANTAS, R.A.; FONSECA, O.P.; GUIMARÃES JÚNIOR, R.G.; FIGUEIREDO, C.C. Chemical composition of cover plants and its effect on maize yield in no-tillage systems in the Brazilian savanna. **Crop and Pasture Science**, v.63, p.1075-1081, 2012. DOI: <https://doi.org/10.1071/CP12272>.
- CARVALHO, A.M. de; COSER, T.R.; REIN, T.A.; DANTAS, R. de A.; SILVA, R.R.; SOUZA, K.W. Manejo de plantas de cobertura na floração e na maturação fisiológica e seu efeito na produtividade do milho. **Pesquisa Agropecuária Brasileira**, v.50, p.551-561, 2015. DOI: <https://doi.org/10.1590/S0100-204X2015000700005>.
- CHENU, C.; ANGERS, D.A.; BARRÉ, P.; DERRIEN, D.; ARROUAYS, D.; BALESSENT, J. Increasing organic stocks in agricultural soils: knowledge gaps and potential innovations. **Soil and Tillage Research**, v.188, p.41-52, 2019. DOI: <https://doi.org/10.1016/j.still.2018.04.011>.
- FIORETTO, A.; DI NARDO, C.; PAPA, S.; FUGGI, A. Lignin and cellulose degradation and nitrogen dynamics during decomposition of three leaf litter species in a Mediterranean ecosystem. **Soil Biology and Biochemistry**, v.37, p.1083-1091, 2005. DOI: <https://doi.org/10.1016/j.soilbio.2004.11.007>.
- HAYES, M.H.B.; MYLOTTE, R.; SWIFT, R.S. Humins: Its composition and importance in soil organic matter. **Advances in Agronomy**, v.143, p.47-138, 2017. DOI: <https://doi.org/10.1016/bs.agron.2017.01.001>.
- MEISINGER, J.J.; RICIGLIANO, K.A. Nitrate leaching from winter cereal cover crops using undisturbed soil-column lysimeters. **Journal of Environmental Quality**, v.46, p.576-584, 2017. DOI: <https://doi.org/10.2134/jeq2016.09.0372>.
- NASCIMENTO, D.M. do; CAVALIERI-POLIZELI, K.M.V.; SILVA, A.H. da; FAVARETTO, N.; PARRON, L.M. Soil physical quality under long-term integrated agricultural production systems. **Soil and Tillage Research**, v.186, p.292-299, 2019. DOI: <https://doi.org/10.1016/j.still.2018.08.016>.
- NASCIMENTO, R.S. de M.P. do; RAMOS, M.L.G.; FIGUEIREDO, C.C. de; SILVA, A.M.M.; SILVA, S.B.; BATISTELLA, G. Soil organic matter pools under management systems in Quilombola Territory in Brazilian Cerrado. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.21, p.254-260, 2017. DOI: <https://doi.org/10.1590/1807-1929/agriambi.v21n4p254-260>.
- PAZ-FERREIRO, J.; FU, S. Biological indices for soil quality evaluation: perspectives and limitations. **Land Degradation & Development**, v.27, p.14-25, 2016. DOI: <https://doi.org/10.1002/ldr.2262>.
- PISSINATI, A.; MOREIRA, A.; SANTORO, P.H. Yield components and nutrients content in summer cover plants used in crop rotation in no-tillage system. **Communications in Soil Science and Plant Analysis**, v.49, p.1604-1616, 2018. DOI: <https://doi.org/10.1080/00103624.2018.1474899>.
- R CORE TEAM. **R: a language and environment for statistical computing**. Vienna: R Foundation for Statistical Computing, 2019.
- RECALDE, K.M.G.; CARNEIRO, L.F.; CARNEIRO, D.N.M.; FELISBERTO, G.; NASCIMENTO, J.S.; PADOVAN, M.P. Weed suppression by green manure in an agroecological system. **Revista Ceres**, v.62, p.546-552, 2015. DOI: <https://doi.org/10.1590/0034-737X201562060006>.
- ROBERSTON, J.B.; VAN SOEST, P.J. The detergent system of analysis and its application to human foods. In: JAMES, W.P.T.; THEANDER, O. (Ed.). **The analysis of dietary fiber in food**. New York: Marcel Dekker, 1981. p.123-158.
- SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.Á. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAÚJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 5.ed. rev. e ampl. Brasília: Embrapa, 2018. E-book.
- SANTOS, I.L. dos; CAIXETA, C.F.; SOUSA, A.A.T.C. de; FIGUEIREDO, C.C. de; RAMOS, M.L.G.; CARVALHO, A.M. de. Cover plants and mineral nitrogen: effects on organic matter fractions in an Oxisol under no-tillage in the Cerrado. **Revista Brasileira de Ciência do Solo**, v.38, p.1874-1881, 2014. DOI: <https://doi.org/10.1590/S0100-06832014000600022>.
- SATO, J.H.; FIGUEIREDO, C.C. de; MARCHÃO, R.L.; OLIVEIRA, A.D. de; VILELA, L.; DELVICO, F.M.; ALVES, B.J.R.; CARVALHO, A.M. de. Understanding the relations between soil organic matter fractions and N₂O emissions in a long-term integrated crop-livestock system. **European Journal of Soil Science**, v.70, p.1183-1196, 2019. DOI: <https://doi.org/10.1111/ejss.12819>.
- SILVA, A. do N.; FIGUEIREDO, C.C. de; CARVALHO, A.M. de; SOARES, D. dos S.; SANTOS, D.C.R. dos; SILVA, V.G. da. Effects of cover crops on the physical protection of organic matter and soil aggregation. **Australian Journal of Crop Science**, v.10, p.1623-1629, 2016. DOI: <https://doi.org/10.21475/ajcs.2016.10.12.PNE164>.
- SOARES, D. dos S.; RAMOS, M.L.G.; MARCHÃO, R.L.; MACIEL, G.A.; OLIVEIRA, A.D. de; MALAQUIAS, J.V.; CARVALHO, A.M. de. How diversity of crop residues in long-term no-tillage systems affect chemical and microbiological soil

- properties. **Soil and Tillage Research**, v.194, art.104316, 2019. DOI: <https://doi.org/10.1016/j.still.2019.104316>.
- SOUSA, D.M.G. de; LOBATO, E. (Ed.). **Cerrado**: correção do solo e adubação. 2.ed. Brasília: Embrapa Informação Tecnológica; Planaltina: Embrapa Cerrados, 2004. 416p.
- SOUSA, R.F. de; BRASIL, E.P.F.; FIGUEIREDO, C.C. de; LEANDRO, W.M. Soil organic matter fractions in preserved and disturbed wetlands of the Cerrado biome. **Revista Brasileira de Ciência do Solo**, v.39, p.222-231, 2015. DOI: <https://doi.org/10.1590/01000683rbcS20150048>.
- SWIFT, R.S. Organic matter characterization. In: SPARKS, D.L.; PAGE, A.L.; HELMKE, P.A.; LOEPPERT, R.H.; SOLTANPOUR, P.N.; TABATABAI, M.A.; JOHNSTON, C.T.; SUMNER, M.E. (Ed.). **Methods of soil analysis**: part 3: chemical methods. Madison: Soil Science Society of America: American Society of Agronomy, 1996. p.1011-1069. DOI: <https://doi.org/10.2134/agronmonogr9.2.2ed.c30>.
- TALBOT, J.M.; TRESEDER, K.K. Interactions among lignin, cellulose, and nitrogen drive litter chemistry-decay relationships. **Ecology**, v.93, p.345-354, 2012. DOI: <https://doi.org/10.1890/11-0843.1>.
- WITTWER, R.A.; DORN, B.; JOSSI, W.; HEIJDEN, M.G.A. van der. Cover crops support ecological intensification of arable cropping systems. **Scientific Reports**, v.7, art.41911, 2017. DOI: <https://doi.org/10.1038/srep41911>.
- YEOMANS, J.C.; BREMNER, J.M. A rapid and precise method for routine determination of organic carbon in soil. **Communications in Soil Science and Plant Analysis**, v.19, p.1467-1476, 1988. DOI: <https://doi.org/10.1080/00103628809368027>.
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